

SCIENCE FOR GLASS PRODUCTION

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SYSTEMS APPROACH TO CONTROLLING SHEET-GLASS PRODUCTION

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A systems approach to controlling the process of sheet-glass production is presented. It provides an integrated solution to the problem of quality control, efficient use of energy and material resources in production, and minimizing negative environmental impacts, including the establishment of safe working conditions. Simulation modeling is used to evaluate the effectiveness of the control problem formulated.

Key words: sheet-glass, process, systems approach, control.

The competitive environment under market conditions forces managers to devote a great deal of attention not only to the production of high-quality, competitive products but also to solving the problems of environmental and worker safety.

The works of the scientists R. I. Makarov, E. R. Khorosheva, V. V. Tarbeev, A. V. Vasil'ev, M. V. Shchukin, D. A. Salman, D. I. Levkovskii, et al. are devoted to questions concerning the control of glass production. Problems of quality control and reduction of the negative impacts of production on the environment and the production workers were solved separately in their works. The operating regimes of the stages of process lines were taken as the controlling actions and the effect of perturbations caused by fluctuations of the batch composition and change of the calorific value of natural gas and the temperature of the environment were taken into account.

Since control and perturbations simultaneously affect glass quality and the degree of impact of the production process on the environment and workers, the control problems listed above must be studied together. This can be done by using a systems approach to control.

The criterion for evaluating the operation of glass plants, just as for any enterprise, is the profit gained over the control time interval. For an existing portfolio of orders for sheet-glass the work-shop cost of glass, which is functionally related to the profit, can be used as a control criterion [1]. The

flows of raw materials and the consumption of fuel, electricity and auxiliary materials are related with the operating regime of the main process equipment and depend on the control actions taken. The fixed costs of production depend little on the decisions made to control the production process. They can be eliminated from the control criterion and attention can be focused only on the technological component of the glass production costs or the technological costs of conducting the process. Analysis of the relative contribution of material and energy flows in the technological component of the costs of glass production by the float method established that large expenditures are associated with the process of melting glass in a tank furnace. They reach 93.3 – 97.8% in the technological component of glass production costs. Expenditures on electricity and auxiliary materials for conducting the technological process in a tank with molten tin and the annealing furnace as well as expenditures on cutting and packaging glass comprise only a small fraction, which makes it possible to treat them as constants and omit them from the control problem [1].

The determining efficiency indicators for sheet-glass production are the specific consumption q of gas for glass-making and the glass utilization factor (GUF). These indicators are calculated from the relations

$$GUF = \frac{G_{\text{glass}}}{G_{\text{mg}}}; \quad q = \frac{Q_{\text{gas}}}{G_{\text{mg}}} \quad (1)$$

where G_{glass} is the output of sheet glass, tons; G_{mg} is the amount of molten glass made; and, Q_{gas} is the gas consumption for melting, m^3 .

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The regime variables, which can be regarded as process-control resources, influence the production efficiency indicators. The profit is maximized minimizing the specific gas consumption and maximizing the glass utilization factor for a prescribed level of production of high-quality glass with constraints on the magnitude of the negative environmental impacts.

Suboptimal expenditures E on energy, raw materials, and material resources in production which are due to high (compared with the norm) specific gas consumption and low glass utilization factor can be evaluated in a money equivalent using the relation [2]

$$E = \left[\frac{C_{\text{glass}}(\delta)}{\delta \times 10^{-3} \times 2.5} + C_{\text{gas}} q \right] G_{\text{mg}} (1 - \text{GUF}), \quad (2)$$

where δ is the thickness of the glass produced, mm; the factor 2.5 is the specific mass of the glass, tons/m³; $C_{\text{glass}}(\delta)$ is the cost of glass with thickness δ , rubles/m²; C_{gas} is the cost of gas, rubles/m³.

The problem of controlling the glass production process in the control range consists in producing high-quality glass with cost-effective use of energy, raw-materials and material resources and minimizing the negative environmental impacts.

We shall describe the formulation of the problem of controlling the production of sheet glass for the example of AGC Bor Glass Plant, JSC. Two polished-glass production lines (1PGL, 2PGL) run at the plant. The processes occurring on the lines are characterized by autonomy. The control criterion of the sheet-glass production processes can be expressed as a sum E_{Σ} of the suboptimal expenditures of energy, raw materials and material resources on the lines 1PGL and 2PGL:

$$E_{\Sigma} = \left[\frac{C_{\text{glass}}(\delta^{(1)})}{\delta^{(1)} \times 10^{-3} \times 2.5} + C_{\text{gas}} q^{(1)} G_{\text{mg}}^{(1)} (1 - \text{GUF}^{(1)}) \right] + \left[\frac{C_{\text{glass}}(\delta^{(2)})}{\delta^{(2)} \times 10^{-3} \times 2.5} + C_{\text{gas}} q^{(2)} G_{\text{mg}}^{(2)} (1 - \text{GUF}^{(2)}) \right], \quad (3)$$

where the superscripts (1) and (2) denote variable pertaining to the first and second process lines.

The control problem is solved using mathematical models describing the dependence of the determining indicators q , GUF and output variables of production Y on the equipment operating regimes W and the production C and environmental F perturbations [1, 3 – 5]:

$$q = \varphi_1(W, C_b), \quad (4)$$

$$\text{GUF} = \varphi_2(W, Y_{\text{glass}}), \quad (5)$$

$$Y = \varphi_3(W, C, F), \quad (6)$$

$$Y = (Y_{\text{glass}}, Y_{\text{n.i}}), \quad (7)$$

$$W = (W_{\text{b.p}}, W_{\text{gm}}, W_{\text{f.r.g}}, W_{\text{an}}, W_{\text{c.o.g}}), \quad (8)$$

$$C = (C_b), \quad (9)$$

$$F = (F_{\text{e.m}}), \quad (10)$$

where Y_{glass} and $Y_{\text{n.i}}$ are vectors of the output glass-quality indicators and negative environmental impact of production; $W_{\text{b.p}}$, W_{gm} , $W_{\text{f.r.g}}$, W_{an} and $W_{\text{c.o.g}}$ are, respectively, the regime variable vectors for the stages of the glass production process — batch preparation, glass making, formation of glass ribbon on tin melt, annealing, and cutting of a ribbon in prescribed formats; C_b is the batch composition vector; $F_{\text{e.m}}$ is the vector of the parameters of the external medium.

The problem of controlling the production of sheet glass is formulated as follows:

minimize the suboptimal expenditures on production

$$\min E_{\Sigma} (q^{(1)}, q^{(2)}, G_{\text{mg}}^{(1)}, G_{\text{mg}}^{(2)}, \text{GUF}^{(1)}, \text{GUF}^{(2)}, \delta^{(1)}, \delta^{(2)}, C_{\text{glass}}, C_{\text{gas}}) \quad (11)$$

with the required glass quality

$$Y_{\text{glass}} \leq/ \geq Y_{\text{pre}}, \quad (12)$$

where Y_{pre} is the vector of the prescribed glass quality, and with constraints on negative environmental impact

$$Y_{\text{n.i}} \leq Y_{\text{n.i.add}}, \quad (13)$$

where $Y_{\text{n.i.add}}$ is the admissible level of negative impacts, by varying the regime variables in a prescribed range

$$W_{\text{min}} \leq W \leq W_{\text{max}}, \quad (14)$$

where W_{min} and W_{max} are the admissible limits of variation of the variables in the control process.

The systems approach to control is used to solve the problem of controlling sheet-glass production in the formulation presented above. This approach with prescribed glass capacity and thickness makes it possible to produce high-quality products (12) with cost-effective use of material and energy resources (11) while limiting negative environmental impacts and securing worker safety (13).

The effectiveness of the systems approach to controlling the production of sheet glass was evaluated by simulation modeling of the control problem formulated above using statistical data on the production of polished glass at AGC Bor Glass Plant, JSC.

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